Does applying nutrient enriched organic matter reduce impact of temporal waterlogging on wheat?

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Abstract
Positive responses to deep placement of nutrient enriched organic matter (NEOM) have been reported in areas where waterlogging frequently occurs. The mechanism responsible for these responses is unclear. A glasshouse experiment was conducted to determine whether the potential interaction between NEOM application and crop responses to temporal waterlogging were related to improved N supply or reduced redox conditions in the root zone. The results showed that under non-waterlogged conditions NEOM, Entec (urea containing a nitrification inhibitor) and foliar applied N produced similar grain yields in wheat, but under waterlogged conditions, NEOM produced significantly greater grain yield than applying Entec and foliar N. The greater growth responses to NEOM corresponded to reduced anaerobic conditions (redox) in the root zone. Application of NEOM appears to improve crop biomass and grain yield under waterlogged conditions by a combination of enhanced N supply and decreased soil redox potential.

Keywords
Nitrogen, Entec Urea, Foliar, subsoil amelioration, anoxia

Introduction
Nutrient enriched organic matter has been thought to increase crop growth by improving soil structure. A recent paper (Celestina et al. 2018), however, has suggested that the primary mechanism underpinning increases in productivity is via enhanced crop nutrition. To date, most research on subsoil manuring has been carried out in high rainfall zone (HRZ) environments on both well-structured soils e.g. Chromosols, as well as poorly structured ones such as Sodosols. Positive crop responses to organic matter (OM) application in this environment could reflect an improved water supply to the crop (allowing it to achieve a higher yield potential) or the widespread occurrence of temporal waterlogging during winter and early spring (MacEwan et al. 2010). In the medium rainfall zone, however, positive grain yield responses to application of nutrient enriched organic matter have been recorded on poorly structured soils (Armstrong et al. 2007; 2015), where lack of soil water almost always limit grain yields, especially during latter parts of the growing season. The common feature of these environments is the incidence of temporal waterlogging, which can occur during critical growth stages and severely limit grain yield on poorly structured soils. Temporal waterlogging has been associated with marked increases in the rates of N loss, presumably via denitrification (Harris et al. 2016), which may explain the proposition of Celestina et al. (2018) that growth responses are primarily via improved nutrition.

A glasshouse experiment was conducted to examine the nature of the mechanism/s regulating crop response to nutrient enriched organic matter under waterlogged conditions, particularly in relation to N supply.

Methods
The experiment was a factorial consisting of two wheat cultivars (Cascades: waterlogging intolerant and Ducula – 4/2*Brookton double haploid cross: waterlogging tolerant), four N treatments (Control, NEOM, Entec urea and foliar N) and two watering treatment (Control: maintained at 70% Plant

available water capacity (PAWC) and waterlogged). There were four replicates of each treatment. The NEOM source was chicken manure pellets applied at 20t/ha. The Entec urea and Foliar N treatments were applied at an N rate equivalent to chicken manure pellets (664 kg N/ha). The control received basal N only.

Soil cores were set up using PVC pipe (40 cm long and 15cm diameter) with 30 cm subsoil and 5 cm of topsoil. To separate the effects of poor soil structure, waterlogging and N supply, a well-structured non-sodic grey vertosol soil (Table 1) was used. Three holes drilled near the bottom of the cores allowed the soil to become waterlogged. The NEOM was mixed as a 4 cm diameter x 20 cm long 'sausage' placed vertically in the centre of the core at 5-25 cm depth. Moist cores were incubated for approximately 6 months prior to commencing the experiment. The Entec urea was applied using the same method, just prior to sowing. Foliar N (UAN) was applied weekly using micro-spray bottles after plants reached the 3-leaf stage. Basal nutrients (N, P, K, Mg, Cu and Zn) were applied to the top layer of soil at sowing and pre-germinated wheat seed was sown, thinned to 3 plants per core at 2 leaf stage. Waterlogged conditions were induced at the 3-4 leaf stage, by placing the cores in a bucket of water with water level just below the soil surface, and through surface application of water. Waterlogging ceased at booting. Shortly after commencement of waterlogging signs of Fe deficiency were observed which was amended by application of foliar $FeSO_4$ solution.

Redox probes (Paleo Terra, Netherlands) measured the aerobic/anaerobic conditions within the soil of the Cascades cultivar. Leaf greenness was measured weekly using a Soil Plant Analysis Development (SPAD) chlorophyll meter. At maturity, plants were harvested, oven dried at 70ºC, weighed and shoot biomass and grain yield determined. Grain and straw samples were analysed for total N content. Root biomass was measured by washing the soil/roots mixture over a sieve, before drying and weighing the root sample.

Table 1. Initial soil properties of the grey vertosol topsoil and subsoil used in the experiment

Soil	pH (1:5 Water)	pH (1:5 $CaCl_2$)	EC (dS/m)	ESP (%)	Organic C (%)	Total N (%)	LSL (%)	USL (%)
Topsoil	8.5	7.7	0.27	4.1	1.5	0.13	20	54
Subsoil	8.6	7.9	0.16	1.4	0.8	0.08	20	50

Results

Early growth responses (i.e. larger plants with darker green leaves) to the different N treatments were evident, under both waterlogged and non-waterlogged conditions. At grain maturity, waterlogging had no significant effect on the shoot biomass in the control treatment, but for all other treatments waterlogging significantly reduced the shoot biomass produced by the wheat plants ($P < 0.001$) (Table 2). The NEOM and Entec urea treatments produced the highest amounts of shoot biomass and were not significantly different to one another. The Entec treatment, however, was more strongly affected by waterlogging, with a 51% reduction in biomass compared to a 31% reduction for NEOM. Shoot biomass produced by the foliar N treatment was intermediate, with waterlogging causing a 32% reduction in shoot biomass.

The NEOM treatment produced the highest grain yield under both the waterlogged and non-waterlogged conditions ($P < 0.001$) (Table 2). Under non-waterlogged conditions the grain yield of the NEOM treatment was not significantly different to that of the Entec urea or Foliar N treatment, but in the presence of waterlogging the NEOM treatment produced a significantly higher grain yield. Temporary waterlogging produced a strong negative effect on the grain yield of the plants grown in all treatments, but particularly the Entec urea treatment where waterlogging resulted in a 74% reduction to the grain yield. In comparison, there was a 37%, 48% and 54% reduction in grain yield of the Control, NEOM and Foliar N treatments respectively from waterlogging. Cascades and Ducula produced a similar grain yield (15.6 and 15.8 g/core, respectively) under non-waterlogged conditions, but in the presence of waterlogging Ducula produced a lower grain yield compared to Cascades (8.1 vs 5.9 g/core) (P = 0.044) (Data not presented).

Table 2. Shoot biomass, grain yield, harvest index, 1000 grain weight, N uptake and root biomass of Wheat grown.

Water treatment	N source	Biomass (g/core)	Grain yield (g/core)	Harvest Index	Grain size (g/1000 seeds)	N uptake (mg/core)	Root biomass (g/core)
Non-waterlogged	Control	24.5	8.1	0.33	42.4	151	3.4
	Entec urea	71.4	18.1	0.25	33.7	770	10.4
	Foliar N	47.0	16.4	0.35	39.7	419	5.8
	NEOM	68.9	20.3	0.29	36.8	576	8.5
Waterlogged	Control	17.5	5.1	0.29	34.2	117	2.2
	Entec urea	34.8	4.8	0.13	19.2	469	4.9
	Foliar N	31.9	7.6	0.23	26.2	321	4.1
	NEOM	47.8	10.5	0.22	30.0	350	5.0
P value (Waterlogging x N source)		<0.001	<0.001	<0.001	0.003	<0.001	<0.001
LSD		7.8	2.4	0.03	3.3	58	1.1

Overall harvest indexes (HI) were low (average 0.26), especially in the waterlogged cores (P <0.001). In the absence of waterlogging, HI was highest in the Foliar N and Control treatments, (P < 0.001) (Table 2). Waterlogging reduced HI, especially in the Entec treatment (49% decrease). Smaller reductions in HI were observed in the Foliar N (33%), NEOM (26%) and Control (12%) treatments. Grain size was highest in the Control and Foliar N treatments, when plants were not waterlogged (P = 0.003) (Table 2). Waterlogging reduced grain size of all N treatments, with the smallest effect on the Control and NEOM treatment and the largest effect on the Entec Urea and Foliar N treatments. The HI or grain size of the two wheat cultivars did not differ under non-waterlogged conditions, but Cascades produced a higher HI (P < 0.001) and thousand grain weight compared to Ducula (P = 0.001) under waterlogged conditions (data not presented).

Temporary waterlogging had no significant effect on shoot N uptake in the Control treatment, but significantly reduced shoot N uptake for all other N sources (P < 0.001) (Table 2). Overall, shoot N uptake was lowest in the Control treatments and highest in the Entec treatments, both under waterlogged and non-waterlogged conditions. Cultivar did not affect shoot N uptake (P = 0.25).

Root biomass was significantly reduced by waterlogging across all N treatments (P < 0.001) (Table 2). The reduction in root growth due to waterlogging was smallest in the Foliar N and Control (30 and 36%, respectively), which also produced the lowest root biomass under non-waterlogged conditions. Waterlogging had the biggest effect on the root growth of the Entec urea treatment, resulting in a 53% reduction. Root biomass of the two cultivars did not differ for any N treatment, except the Entec urea treatment where Ducula produced more root biomass than Cascades (P = 0.028) (data not presented). Root biomass was lowest in the Control treatments, followed by the Foliar N, then NEOM. In contrast to many of the above ground measurements, Ducula produced significantly more root biomass than Cascades under the non-waterlogged conditions, but in the presence of waterlogging there was no significantly difference between the cultivars (P = 0.008) (data not presented).

Results from the redox probes showed significant interactions between time and waterlogging (P < 0.001) or N treatment (P = 0.015), but the three-way interaction was not significant (P = 0.265). The main effect of N treatment by waterlogging showed no difference in redox potential when cores were not waterlogged, but under waterlogged conditions the NEOM treatment showed a significant higher redox potential than the other N treatments ($P = 0.019$).

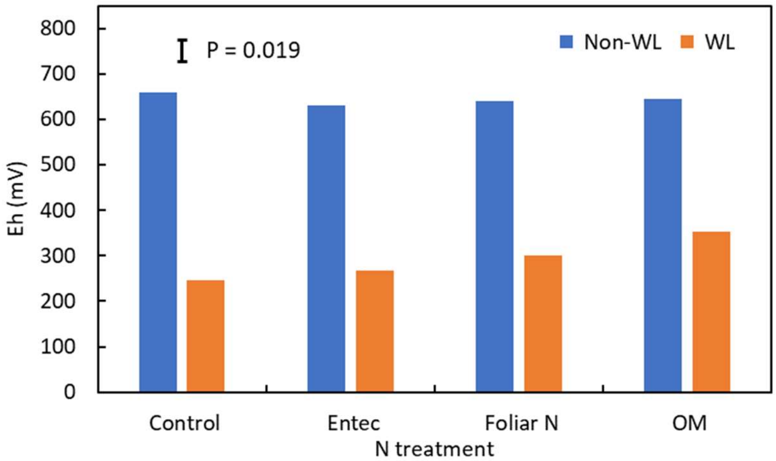

Figure 1. Average redox potential of four N treatments in the presence or absence of waterlogging (over 37 days).

Conclusion

In the absence of waterlogging there was little difference between the N application strategies; they all produced higher yields than the control. Under waterlogged conditions, however, application of NEOM to the subsoil helped plants to produce higher yields than the other N treatments. The NEOM treatment appeared to be able to better maintain root growth in the presence of waterlogging compared to the Entec urea treatment and showed increased root growth compared to Foliar N under waterlogged conditions. Improved growth under waterlogged conditions appears in part to be related to reduced anoxic conditions. Further experimentation is needed to confirm these results.

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